# CHAPTER 4

# RIVER SEDIMENTATION

## Section I. Introduction

4-1. Purpose. The purpose of this chapter is to identify potential river sedimentation problems, to associate those problems with project purposes, and to propose approaches for analyzing them.

4-2. Scope. This chapter points out potential problems, offers guidance in selecting methods for their analysis, and cites available references for details in the field of Sedimentation Engineering. The scope of this chapter includes topics which were selected because of known problems and not for completeness of scientific knowledge. The thought processes for diagnosing sedimentation problems are given in an effort to separate the problems from the symptoms one sees in the field. Sedimentation problems associated with flood channels, navigation channels and permitting are presented in detail because of the mission of the Corps of Engineers; however, the concepts in this manual are not restricted to use in those problem areas. The steps required for conducting river sedimentation investigations are listed, and data requirements are itemized. Maintenance requirements are emphasized.

4-3. Philosophy of the Sedimentation Investigation. The two aspects of the investigation are

a. the impact of sedimentation on project performance, and

b. the impact of the project on stream system morphology.

The impact of the project on stream system morphology should not be determined by comparing a static condition of the stream system, as depicted by either current or historical behavior, to a "future condition with the proposed project in operation". A more appropriate measure of impact is to compare the "stream system with project" to a "future base condition." The future base condition is determined by forecasting the stream system without the proposed project, i.e., a "no-action condition." The "with project forecast" is made for a period equal to the project life. The "no-action forecast" should be made for the same period of time and should contain all future changes in land use, water yield, sediment yield, stream hydraulics and basin hydrology except those associated with the proposed project.

## Section II. Evaluation of the No-Action Condition

4-4. Regime of the Natural River. Natural stream characteristics are the result of "natural forces" interacting with "natural resistances" so "natural changes" occur in a very systematic way. However, because the natural forces are not constant with respect to time and the natural resistances are heterogenous in both time and space, the natural changes contain fluctuations which require careful attention and investigation because they are difficult to understand and predict.

a. Stream Characteristics. "Stream characteristics" refer to channel dimensions, roughness, plan-form and position on the flood plain. In this document a natural river channel is considered to have six degrees of freedom: width, depth, slope, hydraulic roughness, plan-form and lateral movement of the channel bank.

b. Natural Changes. The term "natural changes" refers to the day in day out processes of bar building, bank erosion, lateral shifts of the thalweg alignment, aggradation of the channel bed, and degradation of the channel bed. These changes occur naturally whether man is present or not, but man's activities can accelerate as well as decelerate or completely reverse the behavior of the natural, dynamic stream system.

c. Natural Forces. Natural forces being imposed on a river system are the inflowing water discharge hydrograph, the inflowing sediment concentration hydrograph, the inflowing particle sizes in the sediment concentration hydrograph, and the downstream water surface elevations. These are imposed forces in that a reach of stream channel is being "loaded" by water and sediment from outside the reach. It can be from the upstream reach, from local runoff, or from tributaries. In addition to the inflowing conditions, there is the downstream stage hydrograph. It is a loading parameter in subcritical flow because the downstream stage controls the rate of energy dissipation in the reach. The tailwater can be a friction or contraction control; it can be another river, a lake or the ocean; or it can be a regulated boundary condition like a reservoir. There will be occasional geotechnical failures land slides which load the channel with sediment, but those are not associated with river hydraulic processes and, therefore, are not discussed in this manual. Floating debris is not considered a "natural force" in this manual, but it can severely impact the behavior of a stream channel.

d. Dependent Variables. In this manual the dependent variables are considered to be the six degrees of freedom presented in the paragraph, "stream characteristics." The independent variables are the natural forces - the imposed forces, discussed in the previous paragraph. The end product of a sedimentation investigation is the predicted reaction of each of those dependent variables in each reach of the channel to the aggregate of forces from the independent variables. The behavior of each reach depends on the reaction of the reach just upstream from it. This interaction is referred to as the "stream system concept." The concept of independent and dependent variables also suggests that one should not expect a constructed channel to perform without maintenance unless there is a corresponding change in the forces being imposed on the system.

e. System Behavior. Although the complete theory is not yet available, empiricism suggests that the six degrees of freedom change in system-like fashion as each reach of the river responds to the load being placed upon it from the upstream reach, from tributaries and from lateral inflows. Likewise, a reach of the river will modify the inflowing loads and pass a slightly different set of loadings to the next reach downstream. The concept of changes occurring with time is an important one. Rather than studying streams at only one fixed point in time, the engineer must view the stream system as one of dynamic equilibrium in which channel width, depth, slope, bed roughness and alignment are continually changing.

4-5. Symptoms of Channel Instability in the Project Area. For a given project the identification of the study requirements begins by defining the boundary around the project area and the boundary around the study area. Classifying historical trends of channel behavior within that boundary, during the engineering time scale not geologic time, is one method for assessing the stability of the preproject channel. The criteria for performing such an analysis for channel design can be built around the six degrees of freedom of river behavior. Fluctuations in those values are normal, however, trends to change from one regime to another over time suggests channel instability. It would not be safe to use the present river as the model for a stable channel when such trends are present. Therefore, a more detailed analysis should be made.

4-6. Natural Sedimentation Processes. When forecasting the future base condition of the stream system, strive to quantify the following:

a. location and rate of bank erosion,

b. location and rate of bed erosion,

c. location and rate of deposition,

d. lowering or raising the base-level of the stream system water surface elevations,

e. channel width, depth and slope,

f. turbidity,

g. water quality aspects of sedimentation,

h. shifting location of deep-water channels,

i. head-cutting of the approach channel,

j. head-cutting up tributaries,

k. aggradation of the exit channel, and

l. local scour at bridges and hydraulic structures.

These problem areas are not an exhaustive list. They are included because substantial resources have been expended to correct them at existing projects, and consequently, they should be considered in all sedimentation studies. Each project will likely have its own unique problems which will need to be added to this list.

4-7. Bank Caving. Bank caving is a major consideration from two perspectives: in natural rivers there is the loss of adjacent land with the associated introduction of sediment and debris into the stream; and in project reaches there is the possibility of project failure and of removal of land outside the right of way.

a. Erosion Mechanisms. Stream banks are eroded by hydraulic forces imposed by the channel flow, by waves, by local surface runoff cascading down the bank and by geotechnical processes. Erosion from surface runoff is generally a local scour problem and will not be discussed here.

(1) Hydraulic forces. When bank erosion occurs because water flowing in the channel exerts stresses which exceed the critical shear stress for the bank soils, the erosion mechanism is attributed to hydraulic forces. Two cases are proposed:

(a) tangential shear stress caused by drag of the water against the bank, and

(b) direct impingement of the water against the bank.

(2) Erosion from waves. Boat waves can create bank erosion in confined reaches. Wind waves deserve attention in areas having long fetches.

(3) Geotechnical failures. Often, caving banks are due to bank slope instability and not to hydraulic erosion.

(a) A common cause of geotechnical failure is hydrostatic pressure in the soil column. When the hydrostatic pressure in the soil column becomes equal to that of the water-surface in the channel , and the river stage falls more rapidly than the pressure can equalize, a geotechnical failure of the bank will occur.

(b) Another cause of geotechnical failure is rainfall or snow melt water which percolates into the soil column only to reach an impervious clay lens and be diverted to the stream bank. Proper control of bank drainage will correct the problem in these cases.

(c) A third cause results from degradation of the stream bed causing bank heights to increase beyond the stable value for the bank slope.

b. Erosion Rates and Quantities. There is no theory for predicting the rate of bank erosion of a channel.

(1) Rates of bank line movement. That process is normally quantified from aerial photographs. Periodic overflights are traced onto a common base and the bank movement is measured and converted to units of surface acres lost per mile per year. A more precise technique for observing the rate of lateral movement of the bank line is to establish a base line with ranges from it to the bank. However, the aerial mosaics are sufficient.

(2) Volumes of sediment eroded from the bank. Once the surface area is known, bank heights from the field reconnaissance or from channel cross sections, can be used to calculate volumes of sediment eroded.

(3) Weight of sediment eroded from the bank. The specific weight and particle size gradation are both needed from field measurements to calculate sediment yield by grain size class.

c. Destination of Bank Sediment. Whether or not the sediment eroded from the bank is being transported away by the flow can be determined by the appearance of the toe. If a talus is present and covered by tree growth, the bank is not active. Sediment which fell into the stream is being left there. If the bank is steep to the toe, the sediment falling from the bank is being transported away. That bank is active.

d. Field Reconnaissance. As described in the section on river morphology, lateral movement of the channel is one of nature's degrees of freedom. That is, bank caving will occur even though the net channel width remains constant. In all cases, however, make a careful inspection of the site to determine the failure mechanism (Appendix E). Include personnel from hydraulics, geotechnical and environmental disciplines on the field inspection team.

(1) Channel bends. Inspect the point bar for sediment deposition which is pushing the channel flow toward the outside of the bend. Normal channel meandering is expected to move the channel in the downstream direction. A hard point will interrupt that process.

(2) Gravel bar movement. In gravel bed streams, it is common to view a train of gravel bars moving down the channel. The front of each bar is at an angle with the center line of flow, and that angle swings back and forth from one bar to the next. These bars are probably set into motion by the higher flows, but when the flow is relatively low the front of the bar directs current into the bank line. Because the successive bars are angled toward alternate banks, the flow attacks first one bank then the other. The attack moves along the bank as the bars move down the channel.

(3) Increase in channel width. When both banks show erosion with no accompanying degradation with a resulting net increase in channel width, suspect an increase in mean annual water discharge or an upward shift in the flow duration curve. The channel is adjusting to that new flow regime. Such bank erosion is being produced by a completely different mechanism from bar-building, gravel bar movement or bank failure.

(4) Seepage. Inspect the bank line for seepage, for clay lenses, for slope failure lines, and for tension cracks. Tension cracks suggest the bank height is too great for the soil to be stable on the current bank slope.

(5) Dispersive clays. A type of clays exist, known as dispersive clay, which lacks the cohesive attraction common to most clays. Their permissible velocity is considerably below the range normally quoted for clay material. When making the field inspection, suspect such a clay where rills are cut

deeply into a bank of clay material or into mounds of clay which have been excavated from a channel. Therefore, the engineer should beware that the presence of clay banks does not guarantee that bank material can resist high shear stresses or velocities.

(6) Farming or maintenance practices. Farming or maintenence practices which clear off native vegetation right up to top bank will accelerate bank caving unless over-the-bank drainage is controlled. The process is aggravated by, and should be attributed to, the poor farming practices.

(7) Access/egress points. Cattle or vehicle access to the channel weakens the soil structure and removes native vegetation. Bank erosion often results. The problem typically migrates both upstream and downstream from the initial point of disturbance.

4-8. Channel Bed Scour and Deposition. Changes in the bed elevation because of scour and deposition are classified as local scour and deposition or general scour and deposition.

a. Scour.

(1) Degradation. Degradation is the term describing a general lowering of the stream bed elevations due to erosion of the bed sediments.

(a) Reduction in sediment supply.
The significance of the trend is often masked by the slow rate of growth, but a degrading stream is a potentially severe problem which should be investigated to discover the cause and develop a solution. For example, sediment deficient water released to the channel downstream from a dam has the potential to cause generalized scour. When inflowing water is deficient in sediment of the size classes forming the bed, degradation will start at the point of inflow and move in the downstream direction.

(b) Base level lowering. Another common type of degradation is head cutting. Head cutting is a discontinuity, i.e., a rapid drop or waterfall, in the stream bed profile which moves in the upstream direction. It occurs when the channel bed sediment is weakly cohesive and the base level of the stream is lowered. Head cutting is an important consideration because it promotes bank caving; it causes bridge failures as well as failure of other structures in its path; and it increases the sediment discharge into the receiving stream.

(2) Local scour. Local scour is the term applied when erosion of the channel bed is limited, in plan view, to a particular location. It can occur in otherwise stable reaches of a stream as the direct result of a disturbance to the flow field. The maximum depth is difficult to measure since the most severe scour will often occur during the peak flow and deposition will fill in the scour hole as the hydrograph recedes. Local scour should be regarded as a potentially severe problem in any mobile bed stream.

(a) Bridges. Because of their number, bridges are the most frequent location of local scour problems. The process is usually very rapid. Scour gages consisting of drilled holes in the stream bed back-filled with colored sand, brick chips, or chain have been used to measure scour depths.

(b) Drop structures. Local scour shows up as a deep hole flanked by bank caving. Standard drop structure designs require bed and bank armoring to control this type of scour.

(c) Low weirs. Local scour erodes the bank at the abutments causing the structure to be flanked. Prevent flow from short-circuiting by creating long flow paths. Design for low energy losses at initial overtopping.

(d) Miscellaneous. Local scour also occurs at the downstream junction between riprap or revetment and the natural earth channel. Channel training dikes cause local scour.

b. Deposition.

(1) Aggradation. General deposition, like general scour, spans long reaches of a stream. When the concentration of inflowing sediment exceeds the transport capacity of the stream in that reach, the deposition process starts at the upstream end of the reach and moves toward the downstream end. However, there is a feed back loop. That is, as the deposit moves downstream the backwater effect is reflected in the upstream direction which results in more deposition.

(2) Local deposition. Local deposition compares to aggradation like local scour compares to degradation. It refers to a deposition zone that is limited in aerial extent. It implies nothing about the severity of the problem.

> For example, when the channel width expands, transport capacity will decrease. Sand and gravel will deposit as a center bar because the particles are too heavy to move laterally. During the intermediate range of flow depths, this center bar will deflect water toward both banks. If the banks are unprotected, bank erosion would be expected and that would initiate a new plan-form alignment starting at the center bar and progressing downstream.
>
> On the other hand, streams which are carrying silt and clay would be expected to deposit sediment in the eddies formed on either side of the expansion until a narrower stream width is produced.

c. Field reconnaissance. The following symptoms of general aggradation problems are given to aid in assessing the condition of a stream. When other symptoms are recognized, they should be added (See Appendix E).

(1) Plan-form changes. When the plan-form changes from straight to meandering in the direction of flow, with no actively caving adjacent banks and no bar building, the inflowing sand and gravel loads are in balance with the transport capacity of the stream. However, when there is such a plan-form change in the presence of actively caving banks, the inflowing sand and gravel loads probably exceed the transport capacity of that stream reach causing aggradation. When the plan-form changes from straight or meandering to

braided the inflowing sand and gravel loads very likely exceed the transport capacity of that reach.

(2) Meandering. Active meanders, those at which there is active bank caving, are more likely to be associated with an aggrading reach than a degrading reach. Bank caving in a degrading reach is more likely associated with bank failure than with meandering.

(3) Channel avulsions. When a channel avulsion has occurred and there is no evidence of a downstream, hydraulic control, the inflowing sand and gravel discharge exceeded the transport capacity of the stream in that reach and deposition filled the channel causing the water to seek another place on the valley floor.

(4) Local energy gradient. The significant slope in understanding the micro-behavior, i.e. the reach by reach behavior, of sand and gravel bed streams is the reach energy slope not the general slope of the stream.

## 4-9. Methods for Calculating Channel Bed Scour and Deposition.

a. General Scour and Deposition. The locations, volumes, and bed-change elevations are calculated by numerical modeling methods, such as HEC-6, in which the sediment transport equations are coupled with the continuity of sediment equation. The application is discussed in Chapter 6.

b. Head-cuts. The sediment routing models like HEC-6 will identify conditions conducive to a head-cut by locating zones of intense erosion. They will transport sediment across a head-cut; but they will not calculate the rate of upstream movement of the head-cut.

c. Scour at Bridges. Local scour cannot be calculated with aggradation/degradation mathematical models such as HEC-6 or TABS-2. However, such models will calculate the base level for the channel bed. Equations to predict the depth of scour at bridge piers, below that base level, may be found in references [49], [2], and [48]. While the equations vary somewhat, the basic variables are width of a bridge pier, shape of a bridge pier, skew angle of the bridge, depth of flow, velocity of flow, and in some cases grain size distribution of the bed material.

## 4-10. Design Features to Arrest Bank Erosion.

a. Direct Protection. Direct bank protection is applied directly to the bank and includes riprap, gabions, other types of flexible mattresses, and rigid pavement. It is used to prevent further erosion when the erosion mechanism is hydraulic forces. It is used with bank sloping and bed stabilization to provide protection when geotechnical failures are occurring. Such protection usually increases local turbulence and care must be taken that local erosion is controlled at the end of protection.

b. Indirect Protection. Indirect protection is used to alter bank alignment. It includes impervious dikes and pervious dikes and is constructed away from the bank in such a manner to deflect or dissipate the erosive forces of the stream. Care must be taken to insure that deflected currents do not induce erosion at some other location; consequently, it is much more difficult to design indirect bank protection structures than active protection because the 3-dimensional flow and sediment distribution has to be very carefully defined. Passive protection is subject to increased maintenance due to drift accumulation.

c. Grade Control. When bank failure is occurring due to excessive bank height, and not bank erosion due to point bar deposition, grade control that reduces the bed slope can be effective.

d. Section 32 Program. This program was authorized by the Stream Bank Erosion Control Evaluation and Demonstration Act of 1974 (Section 32, Public Law 93-251) [65]. The legislation authorized a five year program which, among other things, consisted of an evaluation of existing bank protection techniques, construction of demonstration projects, and monitoring the projects to determine the most promising methods. The final report is quite extensive and comprehensive. Copies of the report and its various appendices are available from the National Technical Information Service in Springfield, Virginia.

4-11. <u>Design Features to Control Aggradation.</u> The Corps of Engineers engages in preventing aggradation when it impacts on navigation or flood control projects or when special authorities have been assigned by Congress. The approaches are debris basins, maintenance dredging, and stabilization of channels producing the sediment. Of course, erosion control is a viable alternative if permitted in the authorizing documents.

a. Debris Basins. The design of debris basins is discussed in Chapter 5, Reservoir Sedimentation.

b. Maintenance Dredging. Often the most economical method for handling aggradation problems is periodic dredging. Numerical modeling is the computational framework for estimating the location and amount.

c. Upstream Grade Control. These measures reduce the bed material load when there is excessive degradation.

4-12. <u>Design Features to Control Degradation.</u>

a. Drop Structures. The purpose of drop structures is to reduce the energy slope of the channel so the bed shear stress becomes less than the threshold for erosion of the bed sediments. Design details for the structures are found in reference [55]. In addition, the following details are pertinent for assuring the structures function properly.

(1) Spacing. Spacing between drop structures is critical. Be aware that spacing depends on the inflowing water discharges, the concentration of the inflowing bed material sediment discharge, the gradation of those discharges, and the resistance to erosion of particles on the channel bed. It is not satisfactory to assume historical concentrations and particle sizes when designing drop structures to reduce bank caving because the structures, if

they are successful, will reduce the sediment concentration and may even alter particle size distributions. Therefore, develop the spacing with considerable care. Numerical models such as HEC-6 provide the computational framework for setting spacing.

(2) Local scour. The weak link in most designs are the abutments. The stilling basin below the structure will dissipate the excess energy in the water spilling over the crest, but it does not protect the abutments from local scour when water first starts to spill around the ends of the structure. Efforts to protect against flanking have met with varying degrees of success. The most successful designs are those which pass all flow through the structure.

b. Low Weirs . Low weirs are provided to environmentally enhance channels by providing adequate habitat for aquatic species during low flow periods when the channel would normally be dry. The height of these weirs is normally less than one-third of the tailwater depth at the project design flow line. This height insures little or no head loss with the design flow. However, at low flows the low weir acts like a drop structure and must be designed accordingly [4]. Since water does flow around the ends of these structures, protection must be provided to the stream banks to prevent local erosion.

## Section III. Flood Protection Channel Projects

4-13. <u>Sedimentation Problems Associated with Flood Protection Channels.</u> Whereas reservoirs lower flood stages by using storage to reduce the peak runoff discharge, flood protection channels use hydraulic means to reduce flood damages. Design features include levees, flood walls, reduced hydraulic roughness , channelization, cutoffs and diversions. The objectives are to confine the flood stages inside levees or flood walls, to lower the flood stages by diverting part of the flow around the problem area, to lower the flood stage by channelization or to lower the flood stages by reducing hydraulic roughness. A consequence from lowering flood stages is increased flow velocities. All project alternatives affect one or more of the six degrees of freedom of the natural river to some extent. For example, just having a project requires that erosion of the channel banks be prevented.

4-14. <u>Key Locations.</u> Not all locations in a project are equally likely to experience sedimentation problems. Problems are likely to start at the following locations:

a. Braided channels

b. Changes in channel width

C. Bridge or other structures built across the stream

d. Channel bends

e. Abrupt changes in channel bottom slope

f. Long, straight reaches

g. Tributary and local inflow points

h. Diversion points

i. Upstream from reservoirs or grade control structures

j. Downstream from dams

k. The downstream end of tributaries

l. The approach channel to a project reach

m. The exit channel from a project reach

4-15. Maintenance Requirements. Whereas channel improvement refers to improvement in the hydraulic characteristics such as increased conveyance and lowered flow lines, channel deterioration is concerned with deteriorating characteristics such as decreased conveyance or degradation of the bed profile. A man-made earthen channel begins to deteriorate as soon as it is completed. Vegetation begins to grow on the banks, thereby increasing the resistance to flow. In a sand bed channel, bed forms occur which may also increase the resistance to flow. The channel may begin to change its alignment to a less efficient configuration. Bed degradation may occur. These are but a few examples of channel deterioration. Maintenance is required to preserve design capacities. The amount of maintenance depends on how much the design conditions are out of balance with the natural, dynamic equilibrium of the system. In the absence of maintenance, project failure can be anticipated.

a. Maintenance of Organic Debris and Vegetation Control. Organic debris, items such uprooted trees, are carried and deposited by the water. Organic debris control refers to the handling of such items before they become a problem. There have been cases when simply sawing the root ball off the tree would allow both to be washed out of the system with no problems. In other cases, the debris has been removed from the channel and burned. Not only do these activities reduce hydraulic roughness, they eliminate the opportunity for flow to be diverted into a bank by a fallen tree because its root ball got hung up on a nearby bar. In urban areas mowing and live vegetation control are part of the routine, long term maintenance requirements.

b. Maintenance to Remove Deposits from Aggrading Channels. Channel deterioration due to aggradation occurs when more sediment reaches the project than the project channel is capable of transporting. One maintenance requirement is the removal of those deposits to preserve hydraulic conveyance. Otherwise complete blockage of the channel can be expected. This is a long term problem.

(1) Long term maintenance. The volume of dredging is estimated by calculating the average annual sediment yield entering the project reach, calculating the average annual sediment yield the project is capable of

passing and subtracting the two. If the result shows deposition, that value is the average annual dredging that will be required to maintain hydraulic capacity. This approach recognizes that the average annual value will be exceeded by several times if the year is unusually wet. During dry years, no dredging is expected. However, in the long term the dredging quantities will average out.

(2) Design event maintenance. Some maintenance is always expected after a design flood. Bank protection needs repairing. Areas suffering from local scour or deposition need attention. Office records of the average value for streams in the area provide the best information for this maintenance requirement.

c. Maintenance to Prevent Channel Deterioration Due to Degradation. If the comparison between sediment yield entering the reach and that leaving the reach shows erosion, the channel must be maintained to resist degradation.

d. Maintenance to Overbank Areas . If the channel capacity is not preserved, flooding in overbank areas will become more frequent. Sand deposits have become several feet thick over large areas which is quite damaging to agricultural land because very little vegetation will grow on such deposits. If the overbank area is hardwood forest, deposition of a foot or more will kill the trees by suffocation. These problems are usually too great to be resolved by maintenance.

e. Maintenance to Tributaries. If the main channel deteriorates due to aggradation, water surface elevations are raised. This in turn raises the water surface on tributary streams. In steep terrain the effect on land adjacent to the tributary is probably negligible, but in relatively flat terrain the increased water surface elevation at the mouth of the tributary will create backwater effects up the tributary. On the other hand, if the mainstem channel deteriorates due to degradation, then degradation is likely on the tributary.

4-16. Determining the Boundary of the Study Area. The study area for a flood protection project is the extent of the watershed that will be affected by the project, and that is always larger than the project area. The limits of the study area are often difficult to determine because the effect of changes due to the project can extend for a considerable distance upstream and downstream from it. The effects may also extend up tributary streams. Consequently, a large area can be affected by changes along one reach of a stream. In some instances, the boundary may be well defined by control points such as dams or geologic controls. In most instances, the study boundary will not be well defined and the engineer must make a judgement decision. In these cases, the final boundary must be selected after consideration is given to the historical behavior of the river, current behavior, the relative size of the project and the type, amount and location of available data. Points of caution when defining the study area are as follows:

a. Availability of data. If there is no data available for areas outside of the project boundary and time or cost constraints prevent additional data collection, this area cannot, of course, be included in the analysis. That does not relieve the engineer from the responsibility of making a sediment investigation from which the appropriate recommendations for the project can be concluded. Recommendations for data collection should be a part of such a study.

b. Sensitivity of adjacent reaches. The decision to include or not to include these reaches will likely depend on how much the proposed project features deviate from the characteristics of the natural river.

c. Sensitivity of system to changes in project reach. If the project reach is on a small tributary to a larger stream, it may have no effect on the larger stream even though the project causes drastic changes to the tributary. For example, if a tributary contributes 2 per cent to the total sediment discharge of its receiving stream, it would be unlikely that a project that doubled this contribution to 4 per cent would have any significant effect on the receiving stream.

d. Approach and exit channels. Design features for the approach and exit channels to the project reach can return river hydraulics to preproject conditions thereby reducing the size of the study area.

4-17. Design Features to Reduce Flooding. These features are listed in order of there preference from the standpoint of minimizing sedimentation problems. "More or fewer problems" is a relative comparison to what existed in the natural stream before the project was constructed. The philosophy is to leave the natural channel untouched to the maximum extent possible because the natural river is the best model of itself.

a. Levees and Flood Walls. These are desirable design features because they can be constructed without disturbing the natural channel vegetation, cross section or bottom slope. Usually, there is no immediate effect on sedimentation from implementing this type of modification. However, there may be a long-term channel aggradation problem. Numerical sediment modeling is the computational framework for design calculations.

(1) Influence on hydrology. The flood hydrographs will likely peak at higher water discharges because the project has eliminated storage. On the other hand, additional storage is often mobilized under the backwater curve which extends upstream from the project reach. That will tend to offset the impact of the project. A hydrology study is required to determine which controls. The design flow for a project differs greatly from the day to day flows that have shaped the channel . Therefore, the impact of the full range of flow conditions should be evaluated in a sediment study.

(2) Sedimentation problems in the project reach. Always address bank erosion, aggradation and degradation even though changes from historical conditions are expected to be minimum.

(a) The historical rates of bank caving will probably continue with the project in place. Therefore, the need for bank protection must be carefully analyzed.

(b) The percentage of total flow carried in the channel may increase to the point of causing erosion of the channel bed. Shield's parameter is one method for checking stability. A better method is to use a numerical model such as HEC-6.

(3) Influence on the stream system. The water surface profile at the upstream end of the leveed reach is likely to be higher than it was under natural conditions. That will allow sediment to deposit under that water surface profile upstream from the project. At the downstream end of the exit channel the tailwater rating curve will not change from the preproject relationship. That could trigger a deposition zone if scour is permitted in the project reach.

(4) Long term maintenance. If the project is in an aggrading reach of the natural river, continued aggradation should be anticipated in the future. That can be calculated with a numerical model. Another maintenance item is care of the vegetation which will continue to grow. Not only will it cause aggradation by trapping sediment but it will also increase hydraulic roughness.

b. Reduced Hydraulic Roughness. Mowing in urban areas, or clearing and snagging in rural areas, are popular types of channel modification. In the context of this paragraph, vegetative clearing includes clearing and snagging of debris from the channel bed or selective clearing of growing vegetation. Except for those about to fall into the channel, avoid stripping trees from along the top bank line.

(1) Influence on hydrology. The influence on hydrology is subtle but significant. It results from lowering the water surface elevations. When that occurs, flood plain storage decreases. Flood hydrographs leaving the improved reach may have higher peaks than previously.

(2) Potential sedimentation problems in the project reach. The water velocity will increase because of the reduced hydraulic roughness, and channel erosion is a potential problem. If deposition was occurring before the project, it may or may not continue. Numerical modeling is the computational framework to forecast the project condition.

(3) Influence on the stream system. The upstream end of the project reach has a potential for a head-cut because the stage-discharge curve is lower than it was under natural conditions. Tributary streams also have the potential for head-cuts because of the lower base-level in the receiving stream.

(4) Long term maintenance. Sediment deposition and erosion may be different from historical rates because of better transport through the project.

c. Channelization-Natural Boundaries. This channelization refers to lowering the flood stage of the stream by widening, deepening, smoothing, straightening or streamlining the existing channel. One should plan for a detailed sediment study.

(1) Influence on hydrology. The effect is the same as described for levees and flood walls except carried to a greater extent. That is, storage will be eliminated through the project reach and the project will not create a backwater curve in the upstream direction to help regain that loss.

(2) Potential sedimentation problems in the project reach. A channelized project may perform well or the system may fall apart depending on the design. However, it is much more likely to experience sediment problems than either the levee approach or the reduced hydraulic roughness approach. The type of problems and their severity depends upon how stable the natural channel was in the project reach and how much the design channel dimensions depart from regime values.

(a) Width. In general, fewer sediment problems are expected when the design cross section is constructed by cutting one bank or the other but not both banks, figure 4-1. The most common problems arise when the design bottom width is not in regime with the natural system. Perennial streams typically have a low flow channel. If a wide, flat-bottom channel is constructed, a low- flow channel will often develop within it and the meander pattern will allow that low flow channel to attack first one bank of the project channel then the other. Therefore, channel designs for perennial streams should follow the cross section shape of the natural where possible. Ephemeral streams in Southwest United States, on the other hand, often exhibit a wide, flat sand bed and no low flow channel. Designs for those streams should follow that cross section shape.

(b) Depth. A second problem is a design channel that is too deep or too shallow. Depth refers to channel bank height. It is necessary to observe geotechnical factors, but that is not sufficient to achieve good sediment transport characteristics. The depth providing the best performance is that along a stable, alluvial reach of the natural stream. That is often associated with an annual peak discharge approximating the 2-year flood; however, always inspect the streams local to the project to aid in selecting a suitable depth. This approach to the elevation of the compound cross section shape should be balanced with environmental considerations for grass cover on the floodway berm, figure 4-1.

(c) Alignment. A third consideration in design is the alignment of the channel. The best choice is to follow the alignment of the natural channel. If the alignment is changed, it may require protecting the bends; furthermore, if the channel is straightened, bank protection requirements may be increased to include both banks .

(d) Another common problem is a change, between the natural channel and the design bed elevation of the project channel, in the gradation of sediment on the channel bottom. This becomes a problem when the design cuts through a clay lens into a less resistant material which can be eroded by the flow, figure 4-2.

(e) Hydraulics. Channelization collects more of the total runoff into the channel portion of the cross section. Consequently, the flow distribution across the cross section will be different with the project than it was before. Possible erosion of the channel bed should be investigated.

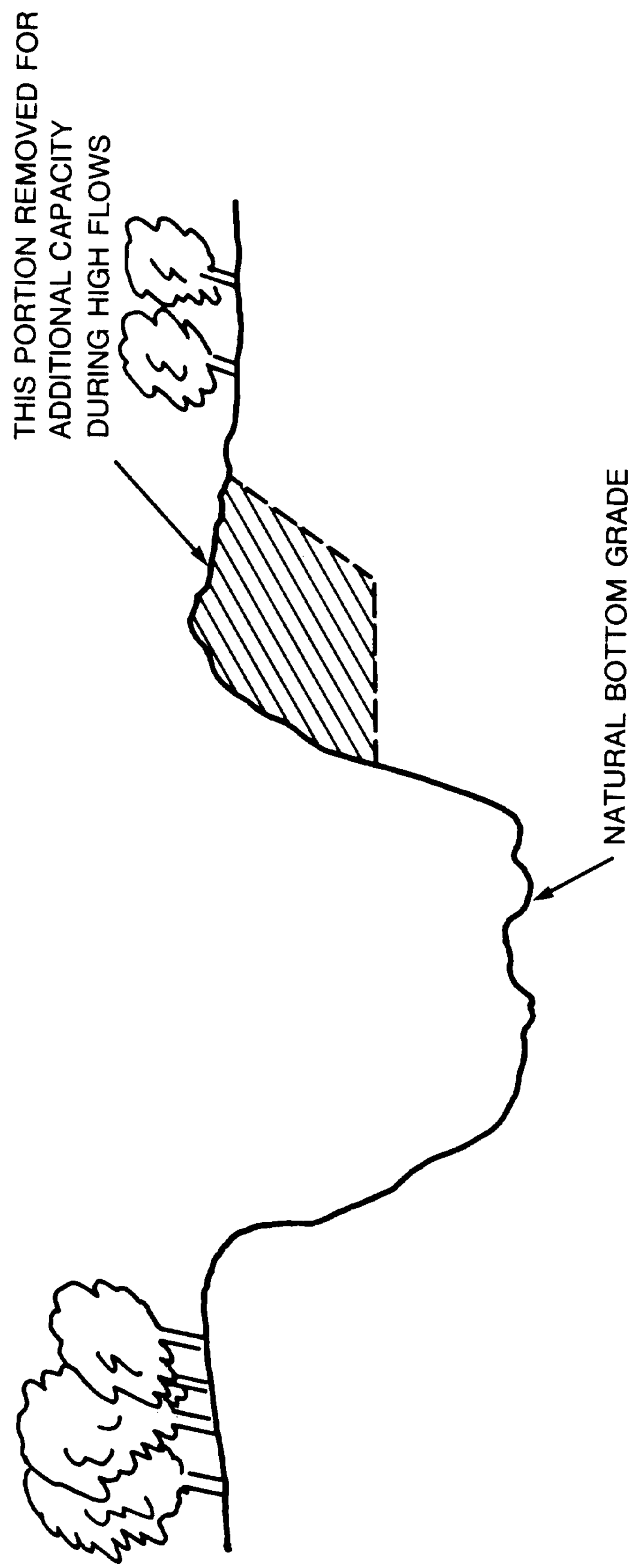



Figure 4-1. Compound cross section shape

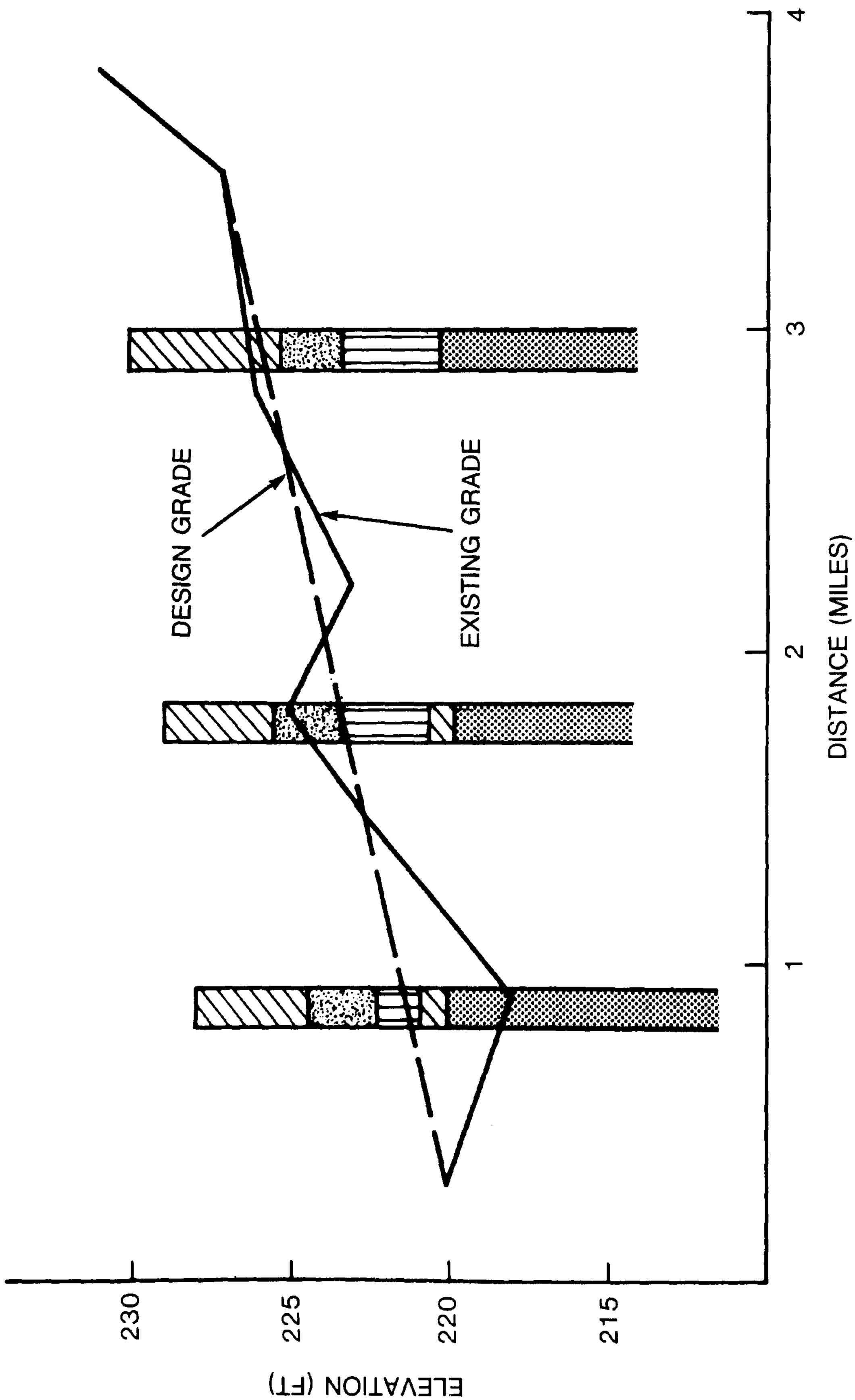



Figure 4-2. Use of boring logs in selecting design grade

(3) Influence on the stream system. Channelization has a more extreme impact on the stream system than reducing the hydraulic roughness does. It is of the same type of impact, however, and that is lowering the base level of the system. Sedimentation problems need special attention in the approach and exit reaches, figure 4-3.

d. Channelization-Rigid Boundaries. This design feature is used to minimize land requirements and protect against the high velocities associated with steep slopes. Measures are similar to those used in natural boundary channelization. The design goal is to maximize channel capacity and minimize flood stages. Erosion is not a problem, but sediments can eventually roughen the channel lining. There is a potential for deposition problems and that needs careful evaluation. Debris basins are common with this design approach.

e. Cutoffs. Channel cutoffs provide immediate and significant reductions in flow lines through and above the cutoff area. To avoid steepening the channel slope, at the low to mid range of flows, high level cutoffs are proposed, figure 4-4. Analysis of the extent of the potential scour and deposition is necessary to insure that the cutoff will function as designed after a new equilibrium condition is established. Numerical modeling is the computational framework for analyzing sedimentation in flood channel cutoffs.

(1) Potential sedimentation problems in the project reach. When all of the flow passes through the cutoff, the usual problem is degradation as the result of a steeper slope. However, when only part of the flow passes through the cutoff, deposition can be expected either in the old bend way or in the cutoff. Erosion of the outside of the bend is probable and a revetment should be considered.

(2) Influence on the stream system. Cutoffs contribute to scour of the channel bed above the cutoff and channel deposition below the cutoff. This process will continue until an equilibrium condition is attained. This equilibrium condition may be unacceptable hydraulically because deposition downstream of the cutoff can significantly raise flow lines. However, the stream will attempt to regain its length, armor its bed, adjust bed roughness, and/or deposit the bed material load with associated bank erosion.

(3) Long term maintenance. Some flood channel cutoffs are high level in that only the flood flows spill into them. To be effective, vegetation and debris maintenance is required. Land use in the cutoff must be restricted.

f. Diversions. The location of the diversion, relative to the bend, point-bar, crossing sequence indicates whether the sediment outflow will be less than or greater than the concentration left behind. Physical models are the most reliable approach for designing diversions.

(1) Potential sedimentation problems in the project reach. As with cutoffs which take only part of the total discharge, deposition is a common problem at diversions. Both local and general deposition are likely. Numerical sediment modeling is the computational framework for predicting

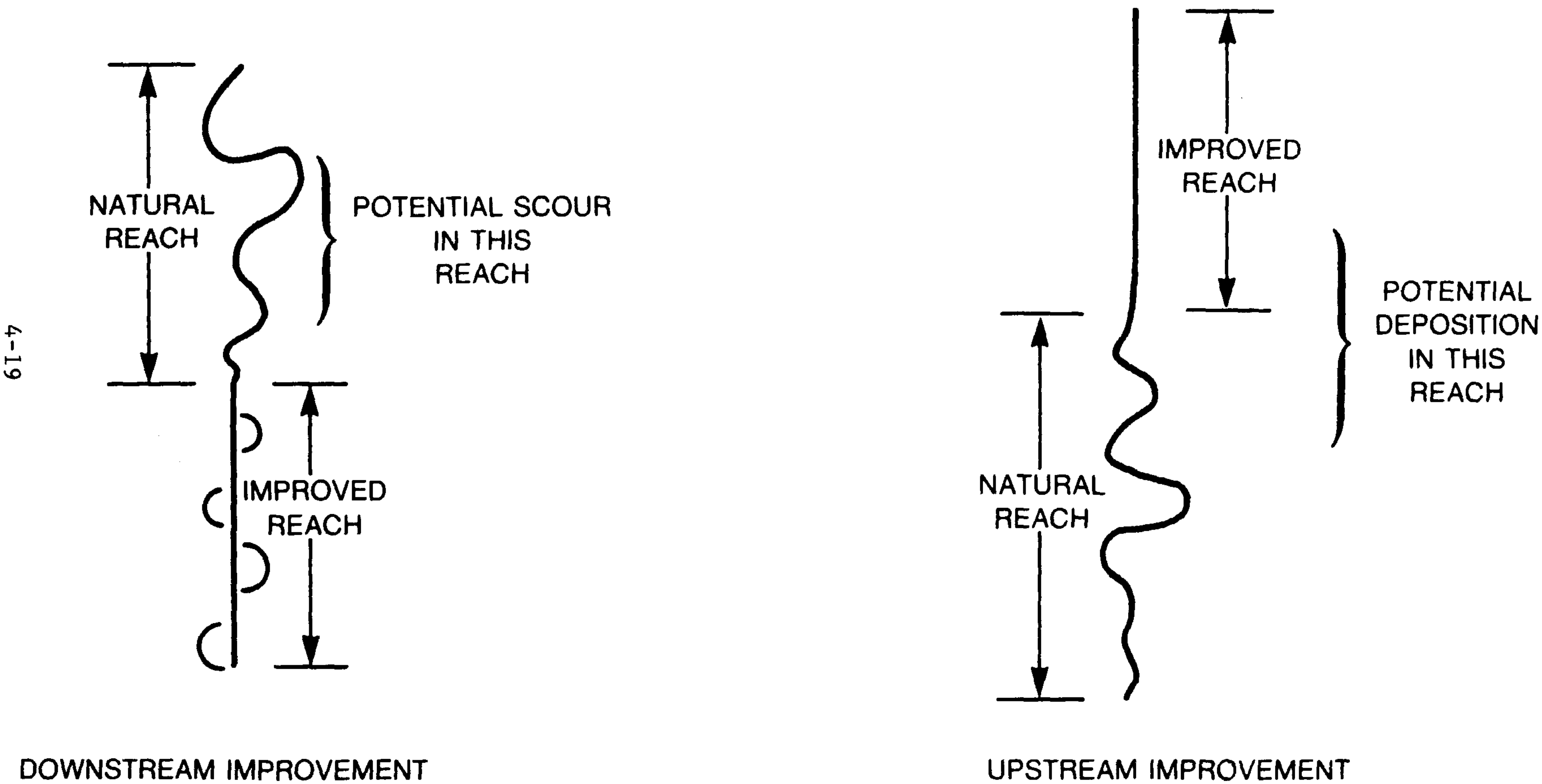



Figure 4-3. Effects of abrupt channel improvement

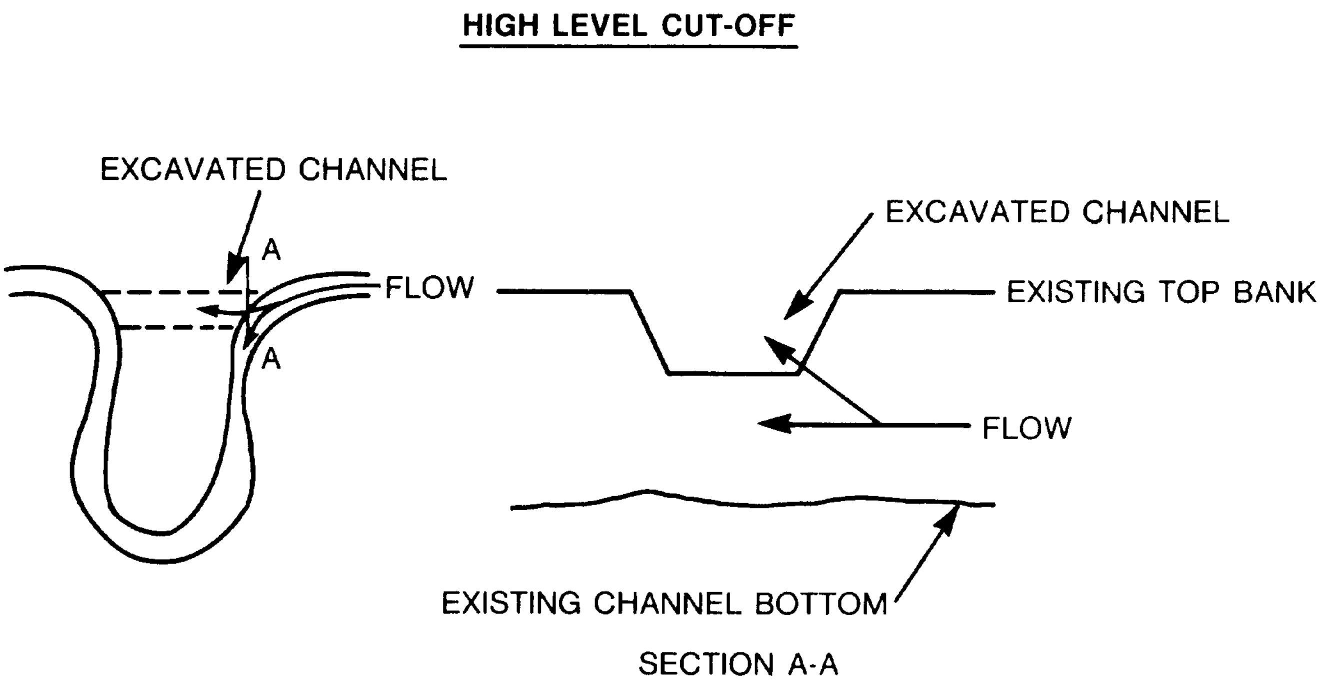



Figure 4-4. Illustration of high level cut-off

quantities and locations of deposits provided the concentration entering the diversion channel is known. Physical modeling is the most reliable approach for predicting the concentration of bed material load entering the diversion channel.

(2) Long term maintenance. The volume of sediment to be removed can be estimated using the sediment budget approach, and numerical modeling will indicate locations of the deposits. Recent cases in which land in the diversion floodway was converted to other uses makes this an unattractive feature because it could not be maintained.

g. Pump Plants. These structures are susceptible to deposition in the inlet channel at the head of the land side pool. Also, once the receiving stream has dropped, the outlet channel of the plant is susceptible to scour since much of the sediment has settled in the relatively slow moving pool water. In these respects, pump plants act like small reservoirs. The engineer should be aware that such drawbacks exist under design conditions.

h. Reservoirs. Although reservoirs are not constructed as frequently now as they were in the past, this is still an important type of channel modification. Reservoir sedimentation is discussed in Chapter 5.

i. Debris Basins. Debris basins are used to reduce the inflowing sediment discharge for those particle sizes which will deposit in the channel project. Design considerations are discussed in Chapter 5, Reservoir Sedimentation.

## Section IV. Navigation Channel Projects

4-18. Sedimentation Problems Associated with Navigation Channels. The objective in navigation channel design is to provide a channel of specified depth and width along an alignment that does not shift from side to side across the channel. Although the water-sediment behavior is similar to that in flood protection channels, the question being addressed is different. A flood project seeks to reduce the stage. A navigation project seeks to provide reliable water depth. The two are sometimes complementary and sometimes competitive requirements. The yield of sand is significant to both. Silt and clay are common materials dredged from navigation channels, whereas silts and clays are not common problems in flood channel studies, except in backwater and salinity areas. Another significant difference between the two channel uses is the resolution required to locate problem areas. Even one shallow crossing will obstruct navigation whereas that probably would not significantly change the stage of a flood. Finally, low current velocities are attractive in a navigation project and that often conflicts with sediment transport requirements.

4-19. Key Locations. Not all locations in a project are equally likely to experience sedimentation problems. Focus on the following locations:

a. Bridge or other structures built across the stream

b. Long, straight reaches

c. Crossings

d. Short radius bends

e. Increases in channel width

f. Tributary inflow points

g. Diversion points

h. Upstream from lakes or streams controlling the backwater curve

i. The downstream end of tributaries

j. The approach channel to a project reach

k. The exit channel from a project reach

4-20. Maintenance Requirements.

a. Long Term Maintenance. The volume of dredging is estimated by calculating the average annual sediment yield entering the project reach, calculating the average annual sediment yield the project is capable of passing and subtracting the two. If the result shows deposition, that value is the average annual dredging that will be required to maintain hydraulic capacity. This approach recognizes that the average annual value will be exceeded by several times if the year is unusually wet. During dry years, no dredging may be needed. However, in the long term the dredging quantities will average out.

b. Design Event Maintenance. Some maintenance is always expected after a large flood. Bank protection and training works need repairing. Areas suffering from local scour or deposition need attention. However, another event to include in sedimentation studies for navigation channel design is the low flow following a flood. A simulation through using the entire flood hydrograph is recommended for leading up to the low flow analysis.

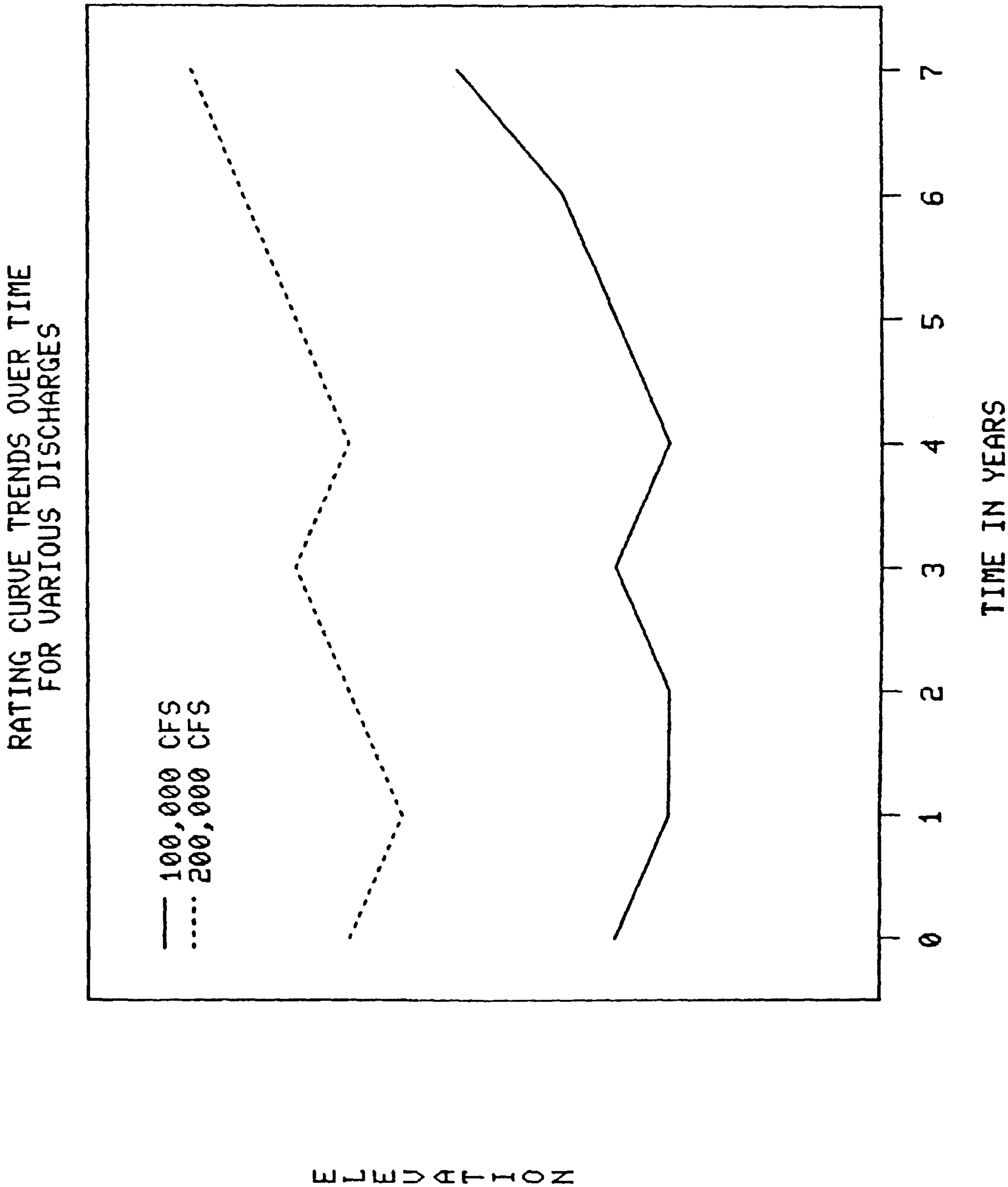
c. Tributary Channel Deterioration Due to Navigation Channel Dredging. When maintenance dredging is so intensive that a lower base-level is perpetuated, bank failure along tributary streams can be expected. A grade control structure at the mouth of the effected tributaries will alleviate the problem by raising the base-level back to the preproject stage-discharge rating curve. Specific gage height graphs will show the extent of base-level lowering, if any, figure 4-5.

4-21. Determining the Boundary of the Study Area. The study area is the extent of the watershed that will be affected by the project, and that is always larger than the project area in the sediment impact assessment study. However, it is possible to decrease the limits of the study area in the detailed studies by collecting sediment data crossing the project boundaries. In some instances, the boundary may be well defined by control points such as dams or geologic controls. In most instances, the study boundary will not be well defined and the engineer must support a judgement decision. In these cases, the final boundary must be selected after consideration is given to the historical behavior of the river, current behavior of the project reach, and the relative size of the project.

a. Data Requirements. The absence of data does not relieve the engineer from the responsibility of making a sediment investigation from which the appropriate recommendations for the project can be concluded. Recommendations for data collection should be a part of such a study.

b. Sensitivity of Adjacent Channel. Reaches adjacent to the project area may not be sensitive areas. The decision to include or not to include these reaches will likely depend on how much the proposed project changes the hydraulic characteristics of the natural river.

c. Approach and Exit Channels. Design features for the approach and exit channels to the project reach can return river hydraulics to preproject conditions thereby reducing the size of the study area.


RATING CURVE TRENDS OVER TIME
FOR VARIOUS DISCHARGES
100,000 CFS
200,000 CFS
ELEVATION
0
1
2
3
4
5
6
7
TIME IN YEARS

4-22. Methods of Analysis. Navigation channel design is more demanding than flood channel projects because the width, depth, location and alignment of the navigation channel are critical. One-dimensional numerical modeling is useful for establishing a "channel trace width" that can achieve a prescribed, long term target quantity of maintenance dredging. Two-dimensional, numerical modeling is useful for designing training works to control expansions and eddys. However, the three-dimensional behavior of flow in sinuous channels requires physical modeling to adequately predict the long term channel characteristics.

4-23. Design Features for Navigation Channels. The following design features start with a stable river channel plan-form and progress to channel modification by cutoffs and chute closures. The structural components used to guide flow in such a way as to maintain an effective main channel along the desired alignment are called training structures. Dikes constructed of either rock or timber piles are most often used. Design details are presented in the engineering manual for layout and design of shallow draft waterways.

a. Navigation Channel Alignment in Stable Reaches. The simpliest problem is one of providing a navigation channel alignment in a stable reach. The proper alignment of the navigation channel will recognize that the bed configuration of an alluvial stream is a series of bends and crossings. It will seek to use that knowledge to minimize maintenance dredging. That is, the bends will have point bars, but both the location and height of the point bars will be fairly consistent from one flood to the next.

> Consistent is not the same as static. Point bars are one of natures locations for storing the bed material load as it moves along the channel. There is a continual exchange of material every flood event. Consequently, bed material which is removed will be quickly resupplied by the next flood event because the bar has to build to its natural height before the exchange process will take place.

Therefore, to minimize maintenance dredging avoid navigation alignments which cross the point bar.

b. Stabilizing or Modifying the Channel Plan-form. A straight channel is not a good plan-form for navigation because the deepest channel shifts around from flood to flood. Training structures can be used to form a meandering pattern within the main channel. However, channel plan-form is one degree of freedom of a river. Therefore, the meander pattern is not an arbitrary sequence of bends and crossings. The river is the best model of itself for establishing the meander wave length and the crossing length. When it is necessary to depart from those dimensions, a considerable effort will be required to establish a successful design.

c. Cutoffs. Cutoffs are constructed to provide a longer bend radius for better navigation conditions. The theory to relate radius of the cutoff to channel width is just developing. Presently, numerical modeling in 1 or 2 dimensions is not adequate to design the cutoff section. The prototype river offers a good model of itself provided one selects bends which are similar to the potential cutoff. Physical models provide the most reliable insight for cutoff design. However, system analysis using a one-dimensional model such as HEC-6 is advisable if the channel length is reduced significantly.

d. Chute Closure. Flow around a center bar or island loses transport capacity and shoaling occurs. The channel is often unstable and requires considerable dredging. Chute closure is undertaken to reduce dredging by confining enough flow to one main channel. The design encourages deposition by slowing the velocities through the chute. This process will be accelerated when vegetation establishes itself on the deposited material.

e. Dredging. Often dredging is the most economical method for providing the required navigation depth, but that should be decided after an analysis of the other design features. For example, channel size and alignment should minimize dredging in bends. Crossings are the usual depth control, and a dredging option would simply keep the crossings open.

(1) Sorting by particle size. Sediment yield studies for navigation dredging should always provide the total volume of material by size fractions.

(2) Influence of dredging on the stream system. Dredging which returns the sediment material to the channel does not create stream system instabilities like dredging which removes sediment from the system. As long as there is a resupply, there will be no lowering of the base level at tributaries. On the other hand, when the stage discharge rating curves show a degradation trend over time, so much sediment is being removed from the system that base level lowering may cause general degradation up the tributaries. That is a system instability which needs attention.

## Section V. Channel Mining

4-24. Channel Mining. The use of stream beds as a source of gravel has increased in recent years. Whichever method is used, gravel mining reduces one of the natural "loading parameters" in the system which can induce significant changes. Bridges have failed after such pits were opened in their vicinity. Therefore, the engineer should be forewarned that such operations should be throughly evaluated prior to their initiation.

4-25. Allowable Quantities and Rates of Removal. There have been no general guidelines established to govern removal quantities and rates. If the stream does not have an excess of inflowing bed material, i.e. if it is not aggrading, then the removal rate and quantity should be no more than the average annual yield of the size classes being removed. When excess material is available in the stream, the removal rate could conceivably be increased, thereby alleviating deposition downstream from the pit. Numerical modeling is the computational framework for establishing quantities.

4-26. Impact of Mining on the Stream System.

a. Upstream. The most common effect upstream from a pit is general degradation with resultant bank failure and channel widening. Such degradation also causes base level lowering on the main stem which can induce general degradation up tributary streams. Prior to approving the pit the depth of channel degradation should be calculated for a distance sufficiently far upstream to ascertain if bridges, and other structures, are adequately founded. Figure 4-6 [37] illustrates a case history in which the San Juan Creek in Orange County, California was adversely affected by a gravel mining operation. In this case the head cutting upstream from the pit eroded the channel bottom to a depth of 30 feet. The overly tall banks failed and the channel became wider.

b. Downstream. Scour has also been observed downstream from some channel mining operations. In theory, this is because the pit traps so much of the inflowing bed material sediment load that the water flowing out of the pit is much like a sediment deficient release from a dam. This sediment starved water removes bed material from the channel. The bed will eventually become armored if sufficient coarse material is present.

## Section VI. Staged Sedimentation Studies

4.27. Staged Sedimentation Studies. Once the study needs have been identified, the engineer must then select an appropriate evaluation procedure. The steps outlined in this section are of general nature; they are offered as a guideline. They are not all inclusive and are given as the least that should be done. The engineer is responsible for supplementing these steps as needed to insure project performance.

4-28. Available Study Approaches. Sediment studies are much like hydraulic studies in that each project has specific requirements. However, sediment studies do share many similarities from project to project. Therefore, while individual studies may vary considerably, the basic approaches are similar. The type of approach depends on several variables as follows:

a. Purpose of the study - question that need answering

b. Physical setting

c. Confidence required in result

d. Data available for the study

The purpose may simply be to determine if a sediment problem does or does not exist in a given reach of stream. On the other hand, the project might be quite complex and the purpose of the sediment study be to calculate as accurately as possible the expected changes in the stream bed and/or sediment discharge during the life of the project. These two extreme purposes require quite different study approaches.

4-29. Sediment Impact Assessment.

a. General. This study approach is recommended as the first step in all sediment investigations. It attempts to discover what sediment problems will significantly affect project performance and/or project maintenance; which "threshold values" might the project cross over that would cause it to fail;

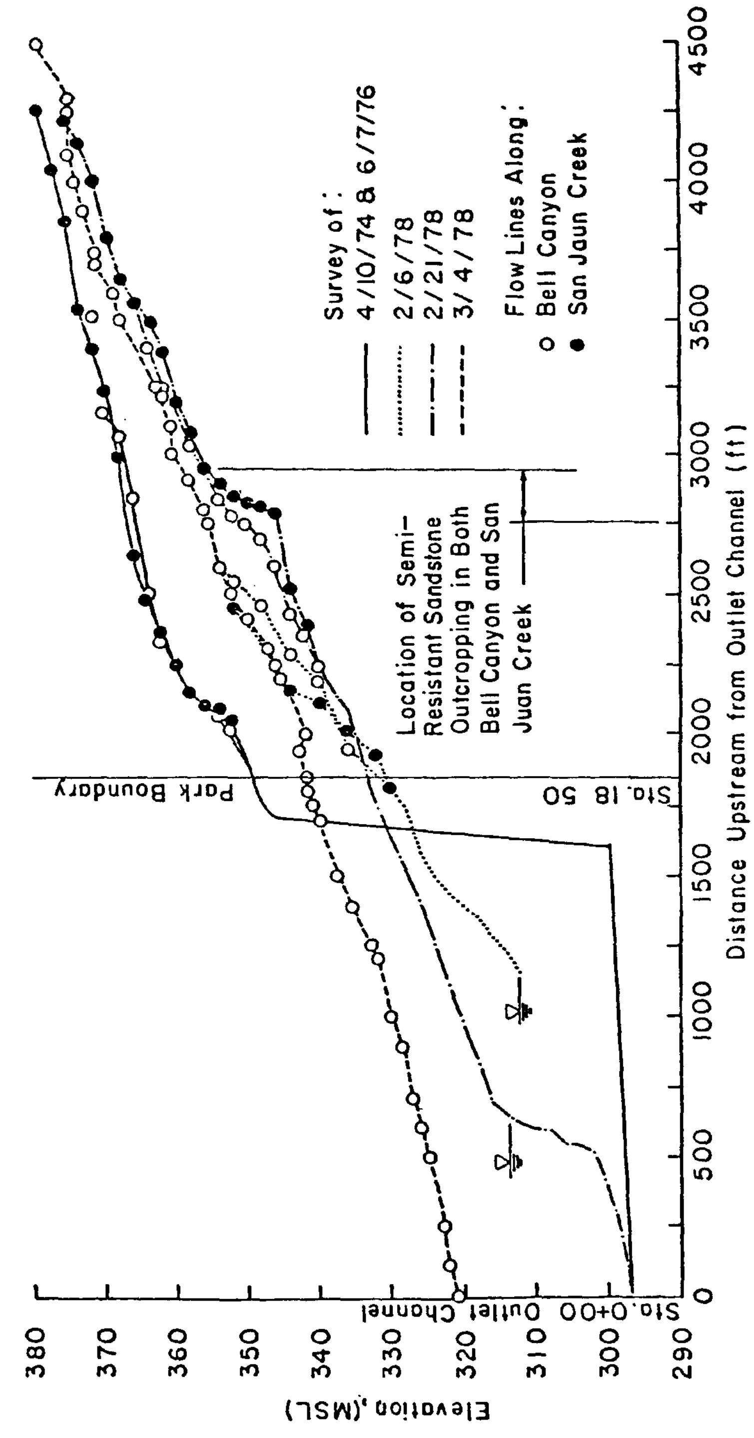



Figure 4-6. Measured bed profiles

which design features of a proposed project may have detrimental effects on this stream; and how severe might those effects be. The sediment impact assessment might suffice for all the sediment investigations required if:

(1) The present reach is stable.

(2) The proposed improvements are minor in nature and do not significantly alter the existing sediment, hydraulic or hydrologic variables.

b. Sequence of Steps.

(1) River geomorphology. Assemble data from all sources. A starting place is the list of sources in Chapter 2 of this manual. Carefully assess the historical stability of the stream system within the project reach, and look both at approach and exit reaches to the project reach. The period of time of interest is the most recent 20-30 years. Refer to Appendix D in this manual for suggested procedures.

(2) Field reconnaissance. Appendix E in this manual has more detailed information on how to conduct a field reconnaissance. The study reach should be inspected to determine if it is stable under current conditions. If it is not, a more complete investigation will be needed, and the Sediment Impact Assessment should recommend what level of detail is appropriate.

(3) Hydraulic parameters for existing conditions. Ideally, these should be obtained from field measurements taken at a standard discharge range. The water velocities, discharges, and water surface elevations are needed to confirm the hydraulic calculations. If that source is not available, use the measurements made on the field reconnaissance to support the hydraulic calculations. In either case the following graphs for the project reach are suggested: a stage-discharge relationship, a depth-velocity relationship, a depth-slope relationship, a depth-bed shear stress relationship, and a depth-percent of total flow in the channel relationship.

(a) Bed roughness. Use a "bed roughness predictor" to tie the hydraulics to the bed sediment samples taken during the field reconnaissance trip. Composite this n value with other roughnesses in the cross section. Plot a graph of channel velocity vs hydraulic radius for the range of water discharges through the project design flood discharge.

(b) Flow distribution between channel and overbanks. Plot the channel velocity from a backwater program for the full range of water discharges. Such a plot should show those velocities increasing with depth. If they decrease with increasing depth, either justify that trend or correct the n-values between the main channel and overbanks before proceeding. Use the channel velocity from the bed roughness predictor as an aid in calibrating the distribution between channel and overbanks in the water surface profile model.

(c) Sensitivity to geometry. If channel characteristics are so varied that one curve is not representative of the project reach, use a water surface profile computer program to calculate the hydraulic parameters. Make two runs: one with the best estimate of n-values from office files; and one using the predicted bed-roughness n-values for the channel bed portion of the cross section.

(4) Sediment transport for the existing conditions. If measured data are available, separate the total sediment discharge into bed material load and wash load components. Otherwise, select a couple of sediment transport formulas and calculate a sediment transport relationship for the full range of water discharges on the stage-discharge relationship. That will provide bed material discharge curves for existing conditions. If the curves are drastically different, apply a third transport function and select the most consistent one.

(5) Plotting of soil borings. It is very useful to plot the channel boring logs on a channel profile. This allows quick identification of potential problem areas. It will also allow design channel grades to be set in such a manner that the channel will be embedded in erosion resistant material rather than cut into soils which are easily eroded.

(6) Develop design features for the proposed project. Friedkin, in his 1945 study, concluded that,

> "... in erodible materials a river will shape its cross sections in accordance with its flow, slope, bank materials, and alignment, irrespective of its initial cross sections, provided the initial cross sections are not so wide and shallow that the flow does not have sufficient velocities to move sand along the bed and erode the banks. Of practical importance, these tests show that in erodible sediments there is no advantage in digging a new channel for a river deeper than is normally found under similar conditions." [20]

The engineer should realize, on the basis of that quotation, that if the proposed, design cross section is not similar to the regime cross section, sediment problems usually require extensive maintenance to keep the project in operation. This concept is valid for both flood control and navigation channels.

(7) Hydraulic parameters for project conditions. Flow line computations are the only source of this information. If the channel is prismatic and flow is friction controlled, simple normal depth calculations will be adequate. Otherwise, use a water surface profile program. Calculate and plot the same variables as presented above for the existing channel. Use the same stage discharge predictor as for the natural channel, but use the bed material gradations at the invert of the proposed channel as well as those from the natural channel and perform a sensitivity study.

(8) Preliminary screening for sedimentation problems. The velocities in the improved channel should not exceed the maximum allowable velocity for the type of material in which the stream is embedded, reference [55]. If they do, either redesign the channel cross section, include a channel lining, or add design features such as drop structures to flatten the slope. Improved velocities for low flows should not be so low that deposition will be induced beyond that which occurs under existing conditions.

(9) Sediment transport for project conditions. Using the same sediment transport formula, calculate a sediment discharge for the full range of water discharges on the stage-discharge relationship. Plot the calculated sediment discharges on the graph with existing conditions.

(10) Impact of sedimentation on performance of proposed project.

(a) General aggradation or degradation. A sediment budget analysis is proposed to test for general aggradation. The budget is calculated by subtracting the sediment yield of the bed material sediment load for project conditions from that for the existing channel. If the result is positive, aggradation is indicated. If the result is negative, check the bed sediment for resistance to erosion. The sediment yield is needed for both existing and project conditions.

(b) Calculate sediment yield for existing conditions. Using some of the methods presented in chapter 3, calculate the average annual sediment yield for the existing channel. Separate that total into the bed material load component and the wash load component. Devise a flow-duration curve for the project site, and integrate that with the calculated sediment transport curve for the existing channel. The result is average annual yield of bed material sediment. Confirm that result with yields determined by the other methods and reconcile differences before proceeding.

(c) Calculate sediment yield for project conditions. Use the flow-duration sediment discharge rating curve method of Chapter 3 and make a sediment yield calculation for project conditions.

(d) Calculate the sediment budget. The sediment budget is calculated by subtracting the sediment yield for project conditions from the sediment yield for existing conditions. If that result is positive, deposition is indicated. Using simple geometries and available specific weights, calculate how much time will pass before deposition is sufficiently deep to affect project performance. If the sediment budget produces a negative difference, erosion is indicated. Choose design features accordingly.

(e) Design flow analysis. Repeat the sediment budget calculation for the design flow hydrograph, also.

(f) Local scour. At this level of study the approach for estimating local scour potential at bridges and hydraulic structures is to compare this project with similar projects.

(g) Bank erosion. Likewise, the approach for evaluating bank erosion and the need for a protective cover is to compare this project with similar projects.

(11) Estimate long term maintenance. This refers to both local and general scour and deposition in the project reach. The approach for estimating maintenance to arrest local scour at bridges, hydraulic structures and bank protection sites, is to compare this project with similar, existing projects. The approach for estimating maintenance for general deposition is

to use the sediment budget analysis.

(12) A numerical sediment model, such as HEC-6 will make all those calculations and display the results in a table using as much or as little data as is available. It is not expensive to analyze a few tracer discharges when an HEC-2 water surface profile data set exists.

(13) End product. Conclude whether the improvements will or will not cause the reach to be unstable. The type and probable locations of design features should be estimated. If the magnitude of sedimentation problems is important to basic formulation decisions, further study should be recommended. However, if the results of this impact assessment can be changed by a factor of 2 without changing the basic go/no-go decisions about the project, it will probably be acceptable to proceed with formulation, initiate a data collection program, and refine the sedimentation investigation in a detailed sedimentation study.

c. Points of Interest if Performing a Sediment Impact Assessment.

(1) Normal depth approach. Hydraulic characteristics can always be determined from flow line computations, but that is not always necessary.

(2) Complex geometry. The study area may be so irregular that the assessment must be adapted to reaches rather than having one for the entire project. Do whatever is necessary to arrive at defendable results.

(3) Sediment transport. Suitable sediment transport equations are listed in reference [2].

(4) Sediment data. Appropriate data necessary for the chosen equations should have been gathered during the field reconnaissance. Ideally, bed samples should be taken at several different times to insure that a representative bed sample has been obtained. One set is better than none.

(5) Study sequence. The first potential area to study is the upstream end of the project reach. When multiple reaches have been used, potential areas of scour and deposition are identified by comparing the transport capacity of a reach to the transport capacity of the next upstream reach.

4-30. <u>Detailed Sedimentation Study.</u> The Detailed Sedimentation study identifies the location and type of project features that will be required to achieve the project purpose with the minimum amount of maintenance. The primary criteria are "What is required for the project to function without major sedimentation problems, and How will those features affect the stream system?" The sediment routing is done by particle size using a numerical sediment model. Several proven models are available and have been used extensively. An example is the HEC-6 generalized computer program, "Scour and Deposition in Rivers and Reservoirs." The differences between this application and that presented in the Sediment Impact Assessment are in the breadth and depth of the computations and the amount of data that is available. In addition, flow hydrographs should be used instead of just a few tracer discharges, and the period of simulation should span from a single event to the life of the project. Sensitivity runs should be made to test the response of the project to uncertainties in sediment yield, water runoff or downstream controls. For these reasons, the study results will provide a better basis for developing conclusions than other computation techniques can provide. The following steps are suggested:

a. Field Reconnaissance. Another field investigation is recommended to visually verify data collected since the previous one.

b. Data Collection. Data necessary for the computer program should have been identified and the data collection effort initiated following the Sediment Impact Assessment recommendations. See the HEC-6 user's manual for specific data requirements.

c. Selection of Transport Equation. The measured sediment data previously collected should be used to select an equation that most closely reproduces the measured data over a wide range of flows. When sufficient data were available, the empirical coefficients in one of the standard transport equations have been calibrated particularly for that study.

d. Preparing Data for the Numerical Model. The data must be organized and coded for input into the computer. One of the largest surprises in sedimentation studies is the amount of time required to code and manage the large hydrologic data sets which are required for long term simulation of a network of streams.

e. Confirmation. Any quantitative analysis should be based on predictive methods which have been confirmed. The confirmation process consists of taking past physical conditions and adjusting the calibration variables until the model will reproduce actual measured changes.

f. Prediction. Upon completion of the confirmation steps, a prediction of bed aggradation and/or degradation can be made with a reasonable degree of certainty.

g. Conclusions. The computer output indicates changes in the channel bottom elevation, thereby highlighting potential problem areas. While the program prints out specific numbers, the engineer must realize that the numbers can only be used for comparison with each other and represent only the "average" future behavior for the project reach. Mathematical models are quite capable of predicting bed elevation changes.

4-31. <u>Feature Design Sedimentation Study.</u> This type of study is an extension of the Detailed Sedimentation Study to test the final design of the project and relocation features. It is usually conducted at a specific location on a stream where extensive data are available. It includes all of the original data plus all data collected since the Detailed Sedimentation Study was completed. Examples are the depth of both local and general scour at bridges; the head loss and potential local scour at weirs and drop structures; the potential deposition in expansions and at inflow points; the performance of debris basins in the design; the stability of the channel invert against erosion; the ability of the approach structure to eliminate head-cuts upstream from the project, the local erosion at the approach structure and the changes in tailwater as the result of changes in the exit channel. Suggested steps are:

a. Field Reconnaissance. A field investigation is necessary to visually verify conditions and data previously collected.

b. Confirmation. At this level of study all hydraulic and sediment parameters will have been comfirmed against field data. The process consists of taking past physical conditions and adjusting the input variables to reproduce an actual measured change. After the predictive equation has been confirmed, the process can be verified by applying it to other data sets and verifying the results.

c. Prediction. The major task is to forecast future land use, hydrology loading and sediment loading. The confirmed model can predict future conditions with a reasonable degree of certainty.